A Public Meeting of the

National Quantum Initiative Advisory Committee (NQIAC)

November 3, 2023

Meeting Minutes

Meeting Participants

Committee Members (in attendance)

- Kathryn Ann Moler, Co-Chair
- Charles G. Tahan, Co-Chair
- Jamil Abo-Shaeer
- Fred Chong
- James S. Clarke
- Deborah Ann Frincke
- Gilbert V. Herrera
- Nadya Mason
- John Preskill
- Mark B. Ritter
- Robert J. Schoelkopf
- Krysta M. Svore
- Jinliu Wang
- Jun Ye

National Quantum Coordination Office Staff Supporting the NQIAC

- Charles G. Tahan, Director
- Gretchen K. Campbell, Deputy Director
- Tanner J. Crowder, Senior Policy Advisor
- Thomas G. Wong, Quantum Liaison and NQIAC Designated Federal Officer (DOE)

Invited Speakers

- Jim Kushmerick, National Institute of Standards and Technology
- Denise Caldwell, National Science Foundation
- Ceren Susut, Department of Energy
- John Burke, Department of Defense

Public Speakers

- No members of the public presented statements

START DATE AND TIME: Friday, November 3, 2023 at 1:00 PM Eastern Time

LOCATION: Virtual Meeting via Zoom for Government

OPENING

Co-Chairs Moler and Tahan welcomed the NQIAC members and the general public. Tahan shared that earlier that day, the Chairman and Ranking Member of the House Committee on Science, Space, and Technology introduced a bill to reauthorize the National Quantum Initiative. He described the NQIAC's previous report as having looked at the National Quantum Initiative as a whole, and that this meeting was so that the NQIAC could look more closely at a specific area: quantum networking.

Clarke asked when he could ask technical questions, and Moler said to use one's best judgment, but to push questions after if possible.

NATIONAL QUANTUM NETWORKING STRATEGY

The first speaker was Tanner Crowder, Senior Policy Advisor at the National Quantum Coordination Office (NQCO) and Co-Chair of the Quantum Networking Interagency Working Group (QN-IWG). His slides, and all the slides from the NQIAC meeting, are available on quantum.gov.[1] He recognized and thanked the other co-chairs of the QN-IWG: Kathy-Anne Soderberg from the Air Force Research Laboratory and Oliver Slattery from the National Institute of Standards and Technology (NIST).

Crowder described quantum information science (QIS) and technology (QIST) as a national priority guided by the 2018 National Strategic Overview for QIS, which has since been augmented by additional strategy documents, including the 2020 Quantum Frontiers report that identified "Generating and Distributing Quantum Entanglement for New Applications" as a key community-identified priority for QIST, A Strategic Vision for America's Quantum Networks that set five- and twenty-year goals for quantum networking, and A Coordinated Approach to Quantum Networking Research that made four technical and three programmatic recommendations. The technical recommendations were to continue research on use cases for quantum networks, prioritize cross-beneficial core components for quantum networks, improve classical capabilities to support quantum networks, and leverage "right-sized" quantum networking testbeds. The programmatic recommendations were to increase interagency coordination on quantum networking research and development (R&D), stablish timetables for quantum networking R&D infrastructure, and facilitate international cooperation on quantum networking R&D.

Crowder described an update to the quantum networking strategy that the QN-IWG would need to submit to Congress by January 1, 2026, as legislated by the CHIPS and Science Act of 2022, and he gave an overview of the Congressionally-mandated components of the report.

[1] All slides presented are available in full online: https://www.quantum.gov/wp-content/uploads/2023/11/NQIAC-Slides-2023-11-03-Draft.pdf

Next, Crowder gave an overview of a June 2023 workshop organized by the QN-IWG, National Science and Technology Council (NSTC) Subcommittee on Quantum Information Science (SCQIS), NQCO, and co-hosted by NASA on quantum networking, which included fifteen agencies, along with national laboratories and National Science Foundation (NSF) Quantum Leap Challenge Institutes (QLCIs) with quantum networking focuses.

Finally, Crowder gave an overview of legislation from the CHIPS and Science Act that focused on quantum networking. In the CHIPS and Science Act, the Department of Energy (DOE) was authorized to carry out an R&D and demonstration program in quantum networking, and NIST was authorized with carrying out R&D to facilitate standardization for quantum networking and communications. In the Consolidated Appropriations Act of 2022 and 2023, the Department of Defense (DOD) was appropriated to explore a quantum networking testbed and a quantum battlefield internet.

After Crowder's briefing, Ritter asked what the most interesting applications were. Crowder responded that there is a great deal of science left to do, and the first applications will likely be in science. Nadya asked what set the timeline for the updated quantum networking strategy report, and Crowder responded that the CHIPS and Science Act is mandating that the report be submitted to Congress by January 1, 2026. Moler asked if agencies are taking a bottom-up or top-down approach, and Crowder responded that they are taking a bottom-up approach given the discovery still needed. Preskill noted that it is really important to have concrete goals for technology development, with one example being the development of a large-scale quantum computer, which has driven investment in fault-tolerant quantum computers and scalable processors. Linking this, he noted a goal for distributing quantum entanglement around the world, but the use cases need more development given the U.S. Government stance on quantum key distribution as an incomplete cryptographic solution, although some quantum sensing prospects are exciting, and he remarked that there is still a need for basic science on transduction, repeaters, etc. Crowder concurred with Preskill's observations that there is a lot of work to be done in the component space. Ritter remarked that his first question was aiming for what Preskill had said. He elaborated that for quantum computing, based on what is known with error correcting codes, more than one cryostat will be needed. He used to work in data communication and technology, and the technology used for wide-area networks is different from what is used for data center networks, such as the frequency of light, and for quantum networking, we need to understand applications so that there is the right technology target.

QUANTUM NETWORKING ACTIVITIES AT NIST

The next speaker was Jim Kushmerick, Director of the Physical Measurement Laboratory at NIST. He explained that NIST's activities in QIS span the full NQI Program, with quantum networking touching many of aspects from computing to sensing. He identified several key quantum networking technologies at NEST, from light sources and detectors, to transducers and repeaters. As an example, Kushmerick described a trapped-ion quantum repeater that entangles a photon at telecom wavelengths with the memory ions, noting that telecom photons are necessary to potentially use existing fiber networks. He then described DC-QNet and NIST's role in the testbed, time keeping, and metrology. At NIST's Gaithersburg campus, several quantum network integration activities are pursued. As a measurement institution, Kushmerick described NIST's efforts in characterizing quantum networks, from state generation to entanglement verification. At the Joint Quantum Institute, a hybrid quantum networking platform with trapped ions and ultracold neutral atoms is being explored. At JILA, efforts to network superconducting qubits is underway. There are also experiments on free-space optical networks, including to network atomic clocks. Finally, Kushmerick described efforts in the Quantum Economic

Development Consortium's (QED-C's) Use Case Technical Advisory Committee, which explores a broad range of QIS use cases, including in quantum networking.

Clarke referred to Ritter's earlier question to Crowder about different classical networking technologies being used for wide-area and local-area networks. He asked if the distance of a quantum network will also affect the technological requirements. Kushmerick replied that the distance most likely does affect the requirements.

Clarke then asked if the QED-C's scope was appropriate, and he expressed the fear that the QED-C is trying to be "everything to everyone" and could be "verry little to anyone." He asked if the advisory committee could look into it. Kushmerick saw no issues with the QED-C's operation, and that while NIST established it and SRI operates it, it is run by the industry members.

Svore asked what the highest risk items were, and the ones with the longest timelines to move forward. Kushmerick expressed that there is a lot of risk in all of the activities and so it is hard to characterize, and NIST's role is to be spread across the space and not pick winners and losers. He thinks transduction is one of the largest problems, and offered to follow up with NIST researchers.

Preskill noted that after over 20 years of research on transduction and repeaters, there is still a long way to get to a useful network. He asked if the community is close to an inflection point or if still faces a "wilderness" of possibilities, and how much longer it might be until an inflection. Kushmerick replied that NIST assumes that a realistic quantum network will need telecom wavelengths, and offered to ask NIST researchers their thoughts on the timeline.

Ye described his perspective on quantum networking. He reiterated that a quantum repeated is needed, but current devices do not have the fidelity to make repeaters useful, that they cannot scale with distance. Besides this challenge, he described transduction as the other limit to quantum networking. He also expressed that while quantum networks will come in time, current leading fundamental science can be pursued with classical networks.

Mason asked how balance is achieved between fundamental research and solving known problems. Kushmerick said that NIST has a distributed portfolio with a focus on both.

QUANTUM NETWORKING ACTIVITIES AT NSF

Denise Caldwell, Acting Assistant Director of the Mathematical and Physical Sciences Directorate at NSF, shared NSF's priority goals in NSF to explore quantum frontiers, accelerate innovation, expand participation, and develop infrastructure. NSF has been supporting quantum networking for decades, from a 1999 QIS workshop to a 2019 quantum interconnects workshop. From 2000 to 2023, they funded over 570 projects on quantum networks for a combined total of $398M, involving 145 institutions, 650 faculty, 410 postdocs, 2530 students, and 1340 publications. Currently, there are 180 active quantum networking awards that started from 2019 to 2023 that total $170M. NSF-funded research has demonstrated transduction from a microwave to an optical photon with greater than 50% efficiency. In 2021, NSF ran the Transformative Advances in Quantum Systems (TAQS) program on quantum interconnects, which involve teams of three or more PIs, resulting in $25M for 10 awards. The

Expanding Capacity in Quantum Information Science and Engineering (ExpandQISE) program has been broadening and increasing participation in QIST. NSF's latest program is the National Quantum Virtual Laboratory (NQVL), which seeks to accelerate progress toward practical quantum advantage through basic science conception, basic technology development, and proof of concept demonstration, followed by a virtuous cycle of scaling/improving technology, application demos, and demonstrating increasing quantum advantage, and ending with full stack integration, user access, scientific applications, and commercial development.

Herrera praised NSF's efforts, that the agency is working on all the important areas and doing what they do best. He raised whether the community is focusing too much on scaling and not enough on fundamental research.

On the NQVL slide, Moler asked about the balance between the first few steps and the last few steps, what scale of investment is needed to push development forward, and if NSF is able to fund at that level. Caldwell agreed that a healthy balance is needed between the first few steps on basic research and later steps on more applied research with feedback to basic research. She also said she agreed that later steps will require a "not insignificant amount of support."

Moler also asked how soon gaps can be identified to help inform the NQVL. Caldwell replied that the first call, focusing on conceptual design, was just issued. More clarity should be available in the spring, and after the second call, additional clarity next fall. She expressed a desire to work in partnership with other agencies.

Quantum Networking Activities at DOE

Ceren Susut, Associate Director of Science for Advanced Scientific Computing Research (ASCR), gave an overview of quantum networking activities at the DOE Office of Science. She stated that QIS is a long-term effort at DOE, and shared a picture of a scientist doing an experiment with entangled photons at a national laboratory in 1972, for which he won the Nobel Prize in 2022. DOE engages in QIS through core basic research, center-scale efforts, infrastructure development, critical supporting technology, and workforce development. Quantum networking specifically has been funded through multiple solicitations since 2019, involving national laboratories, universities, and industry, and projects have developed prototypes and testbeds. Susut shared a slide, without going into details, of various priorities and topic areas for quantum networking R&D. She then shared about several testbeds being developed by national laboratories, in partnership with universities and industry. ASCR's most recent funding opportunity announcement on quantum networking was on Scientific Enablers for Scalable Quantum Communications, including quantum repeater devices, quantum error correction and mitigation in quantum networking, and quantum network architecture and protocols. This resulted in three awards incorporating a variety of institutions. As a science highlight, Sust shared an early career awardee who developed an analyzer with a 98% fidelity for distinguishing between two distinct frequency bin Bell states. Finally, Susut shared about a recent ASCR workshop to identify basic research needs in quantum computing and networking, and a procure and report on the priority research directions are in preparation for release.

Preskill commented on the numerous testbeds at national laboratories and asked if they complement each other and avoid duplication. Susut replied that it is too early to "downselect." Herrera praised the organizational and coordination structure of the DOE Nanoscale Science Research Centers (NSRCs).

Moler asked Herrera to elaborate, and Herrera commented on the original creation of five NSRCs with various focuses, such as metrology, basic science, integrated nano-systems, and fundamental materials. From the start, the key challenges were broken down and structured to feed into each other, with centers relying on each other for the pieces. Susut commented that there are many successful models for centers at DOE. Moler noted that the CHIPS and Science Act authorized DOE to invest $100M in quantum networking, and asked what DOE would do if appropriated the funds. Susut replied that she cannot comment on that at the moment, other than what was shared in the overall plan, such as infrastructure, workforce, and demonstrators. Moler asked Susut if she had any last thoughts. Susut thanked the NQIAC for their feedback, noting that quantum networking is an interesting field with lots of work to do, and the feedback from committee will be useful and valuable.

QUANTUM NETWORKING ACTIVITIES AT DOD

John Burke gave a briefing on research in distributing entanglement at DOD. He began with a framework for quantum science, technology, and engineering at DOD, describing these respective areas as knowledge-driven, applications-driven, and process-driven. Next, he gave four potential uses for distributed entanglement. The first was quantum interconnects, which are meter-scale in length, which he sees as a critical path to full-scale quantum computing. The next was quantum secure communications, which he sees as only a partial security solution. Third was geographically distributed computing, but he questioned the applications of this and raised issues of latency and energy loss. Fourth was imaging with entanglement, which he claimed could have advantage for local interferometers, but perhaps not with long-baseline interferometers without bright single photon sources or large memory buffers. Next, Burke shared a slide with potential applications of distributed entanglement, assessed according to their relevance to DOD's mission, benefits given implementation constraints and concept of operations analysis, performance advantage, and technological feasibility. Based on this, Burke assessed that distributed entanglement currently only made sense for interconnects for scaling quantum computing, but further fundamental research is needed to discover novel applications and assess their practicality. In the next slide, Burke again presented applications of distributed entanglement, this time based on their impact and network node length. Modular quantum computing was the only application assessed with a critical impact, with a network node length is on the order of 100 meters or less. For the remainder of the briefing, Burke gave an overview of quantum networking activities in the U.S. Army, Navy, Air Force, and Defense Advanced Research Projects Agency (DARPA).

Schoelkopf asked about blind quantum computing in Burke's slide assessing it based on relevance to the DOD mission, benefits, performance advantage, and feasibility. He asked why it had question marks under each of the assessments. Burke responded that more directed research is needed to understand how it would be used in a practical sense. Ritter raised the impact that post-quantum cryptography would have on quantum networking, that it could eliminate the need or benefit of quantum key distribution. Burke agreed, that a cost-benefit analysis of quantum key distribution relative to post-quantum cryptography is unfavorable to quantum key distribution. Abo-Shaeer asked how DOD is coalescing around local area networks and given that there are several projects focused on long-scale quantum networking, and what the focus will be. Burke replied that for shorter distance nodes, repeaters will not be as much of a priority, and the priority will be on high-fidelity, low-loss entanglement exchange, as well as interconnects between different types of qubits. He noted that not all service labs are in line with his priorities, and while there is room for debate, there is a need to have conversations on where DOD priorities should be. Preskill pointed out that very long baseline interferometry was marked as technologically infeasible in Burke's slide, and he asked what timescale is being used to assess feasibility, commenting that he thinks the application is important in the long run. Burke referenced a study, whose report has not yet been released, that claimed the challenge to very long baseline interferometry was if a photon arrives at a telescope at an unknown time and frequency, then there needs to be entangled photon resources at all arrival times and frequencies, necessitating a lot of resource states or a very large memory buffer. Moler expressed interest in learning about use cases for quantum networks longer than 100 meters.

Discussion and Adjournment

Tahan shared a couple areas that the NQIAC could look into and comment on. The first was post-quantum cryptography vs quantum key distribution, as well as research in quantum key distribution vs developing it as a product. He noted that the NQIAC's June report included a recommendation about migrating to post-quantum cryptography, and perhaps it could be revisited and expanded upon. The second area was that there is a wide array of activities in quantum networking, but not many focused efforts. He said that getting a few of the technologies over the finish line will require focus efforts, and the NQIAC could look into gaps in funding and the ecosystem to mature technologies.

Moler invited any other final thoughts or summative remarks. Ye made a distinction between scaling up systems locally, for which conditions could be suitable, and scaling up a large-scale quantum network, which may not yet be ready. Moler asked if it is because the applications are not convincing or because the technology to scale is lacking. Ye replied the latter, that higher rates of photons and other technologies to scale are needed. He responded to applications as well, that they are fascinating, but classical systems are superior for the moment, and quantum networks need to beat some thresholds first before scaling.

Wong reminded the public that there is no space in the agenda for public comments because there were no requests for public comment. He pointed guests to the Federal Register notice, which has instructions for submitting formal comments.

Herrera expressed concerns about a lack of sufficient planning. He stated the need for use cases for mission areas, and then programs formulated based on those goals that address key technical challenges. Moler was more optimist, citing the DOD slides as an example of assessing applications, but wondered if other agencies had done similar analyses.

The meeting was adjourned at 3:00 PM Eastern Time.

Certification

I hereby certify that, to the best of my knowledge, the foregoing minutes are accurate and complete.

Kathryn Ann Moler, PhD
Co-Chair
National Quantum Initiative Advisory Committee

Charlies G. Tahan, PhD
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